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Non-Edible Mahua Oil: A Critical Evaluation of Oil Extraction, Methyl Ester Production,Characteristics,and Possibility as Bio-Additive

Abstract

Current world energy consumption is trying to gradually shift away from fossil fuels due to the concerns for the climate change and environmental pollutions. World energy demand is ever augmenting due to thriving urbanization, better living standards and increasing population. Fossil fuel depletion, environmental concerns, and steep hikes in the price of fossil fuels are driving scientists to search for alternative fuels. Biodiesel, an ideal alternative to fossil fuels, is very imperative for the sustainable development of mankind. There are different potential feed stocks for biodiesel production. The use of non-edible plant oils is very significant because of the tremendous demand for edible oils as food source. The chemical-catalyzed transesterification of vegetable oils to biodiesel has been industrially adopted due to its high conversion rates and low production time.However, this process suffers from several inherent drawbacks related to energy-intensive and environmentally unfriendly processing steps such as catalyst and product recovery, and waste water treatment. The present investigation includes Mahua oil alcoholysis using methanol in the presence of acid and alkali catalyst in two steps, hydrolysis of Mahua esters, characterising the properties and standardising the engine performance and emissions as per ASTM specification.

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Keywords: CMO: Crude Mahua Oil., RMO:Refined Mahua Oil, TEO:Transesterified Oil, MME : Mahua Methyl Ester, FFE : Free Fatty Acids, C.R: Compression Ratio, B-10 :Petroleum Diesel: Maua Methyl Ester =9:1, B-20 :Petroleum Diesel: Maua Methyl Ester =4:1, B-30 :Petroleum Diesel: Maua Methyl Ester =7:3, B-50 :Petroleum Diesel: Maua Methyl Ester =1:1, B-100 :Absolute Mahua Methyl Ester,

Introduction

Madhuca indica is mainly found in India [1, 2, 3, 4]. It belongs to the Sapotaceae family and grows quickly to approximately 20 m in height, possesses evergreen or semi-evergeen foliage, and is adapted to arid environments [5, 6]. Madhuca indica is one of the forest based tree-borne non-edible oils with large production potential of about 60 million tons per annum in India. The madhuca indica tree starts producing seeds after 10 years and continues up to 60 years. The kernel constitutes about 70% of the seed and contains 50% oil [7, 8, 9]. Each tree yields about 20–40 kg of seed per year depending upon the maturity and size of the tree and the total oil yield per hector is 2.7 tonne per year, Fig-1. Its seed contains about 35–40% of Madhuca indica oil [10].

Fig.1.Madhuca indica plant fruits and seeds

This study was carried out to investigate the performance and emission characteristics of Mahua Methyl Ester (MME), in a stationary single cylinder, four stroke diesel engine and compare it with mineral diesel. The Mahua oil was blended with diesel in different proportions. Baseline data for diesel fuel was collected. Engine tests were performed using all these blends of MME.

1. Non edible Mahua oil intervene operational and durability problems when subjected to long-term usage in CI engine.
2. These problems are attributed to high viscosity, low volatility and poly unsaturated character of vegetable oils.

This paper is aimed to investigate the glutinous cold flow properties of 100% biodiesel fuel obtained from Madhuca indica. Most of the properties of Madhuca indica ester are comparable to petroleum based diesel; improvement of its low temperature flow characteristic still remains one of the major challenges while using it as an alternative fuel for diesel engines.

The alkyl esters derived from fats or oils with significant amounts of saturated fatty compounds will display higher cloud points and pour points. The cloud point, usually occurs at a higher temperature than the pour point, is the temperature at which a liquid fatty material becomes cloudy due to the formation of crystals and solidification of saturates. Crystallization of the saturated fatty acid methyl esters during cold seasons causes fuel glutinous and operability problems as solidified material clog fuel lines and filters. With decrease in temperature more solids form and material approaches the pour point, the lowest temperature at which it will cease to flow. It has been well established that the presence of higher amount of saturated components increases the cloud point and pour point of biodiesel [11].

A field trial conducted by one of the authors on Mahua Methyl Ester (MME) fuelled CI engine for 200 hours resulted in a considerable clogged filter. On the other hand, the diesel fuelled CI engine for the same duration shows a considerably clean filter. The clogged MME fuelled filter weighed 30% more than that of the diesel fuelled CI engine filter after 200 h of operation,

Fig-2.

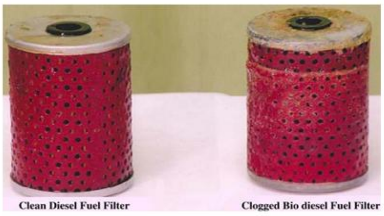

Fig.2.Filter clogging with 100% MME

C.W. Chiu [12] reported that solutions to minimize clogging of fuel filter include pre heating of fuel tank,fuel line and fuel filter heaters; utilization of additives (pour point depressants, anti-gel additives or cold flow improvers) that enhance the impact of crystal morphology; and blending with a fuel like kerosene which causes freezing point depression.

Aim of the Study

The present study was carried out to optimise the oil extraction and its conversion to methyl ester, characterization of the mahua methyl ester properties as a fuel and evaluation of engine performance. The result shows that B-10 and B-20 was the best engine fuel in D.I engines without any change in engine hardware.

Review of Literature

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Materials and Methods

Removal of Gums and Alkaloids

The crude Mahua oil was centrifuged at 8500 RPM in a REMI Model-24 centrifuge machine and the super natant oil was collected free from heavy contaminates. 25 ml methanolic $H_3 PO_4$ solution

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(12%, v/v) was homogenized with 100 ml crude oil and allowed to stand for overnight. Next day, the oil was separated from methanol layer and precipitated compounds are filtered through silica gel (60–120 mesh) under suction. The filtrate, consisted of methanol and phosphoric acid, could be recycled three times for degumming Mahua oil. This makes the process economically more viable. After degumming, oil was kept overnight with 0.1% aqueous sodium hydroxide solution. Next day, aqueous portion was discarded and oil was washed twice with water to remove residual alkali. Then oil was heated on boiling water for 1 hour and then passed through warmed (warmed at 105^0 C in an oven before use) anhydrous Na_2 SO_3 to remove moisture from oil. Resultant oil was stored as refined alkaloid-free Mahua oil (RMO).

After the whole process, up to 94% of the CMO was converted to RMO.

Esterification

For esterification, degummed and alkaloid free oil (RMO) was mixed with sulphuric acid and methanol in the proportion of 50:10:1 (oil: CH_3OH:H2SO4, v/v/v) and stirred mechanically at 1000 rpm at 65^{0}C for 3 hours. After completion of esterification process, two layers were separated within 30 min. The lower layer was discarded and followed by neutralization with methanolic costic soda solution and methanol was recovered from oil. The neutral oil was then mixed with sodium hydroxide and methanol in a ratio of oil:alkali:methanol (25:0.2:5) and stirred well mechanically at 800 rpm for 4 h at 55^{0}C. After transesterification, oil was separated from lower layer by separating funnel and washed with water twice to remove impurities, and resultant transesterified oil (TEO) was stored for further analysis. After two-step transesterification, 87% of the RMO was converted to TEO.

Experimental Setup

ASTM D-97 Pour Point Procedure [13]

The pour point is the temperature at which the fuel can no longer be poured due to gel formation. The observation of the samples starts at a temperature that is at least 9^{0}C above the expected pour point. The sample was immersed into an -18^{0}C cooling bath. If the sample not ceased to flow when its temperature has cooled to -6^{0}C, the sample then transferred to -33^{0}C cooling bath.

Readings were taken for every 3^{0}C decrease in the temperature until the sample totally ceased to flow (the sample was held in horizontal position for 5 s). Readings of the test thermometer were taken and 3^0 C was added to the temperature recorded as the result of the ASTM D-97 pour point.

ASTM D-2500 Cloud Point Procedure [14]

The cloud point is the temperature at which a cloud of wax crystal first appears in a liquid when it is cooled under controlled conditions during a standard test. The same cooling procedure as described in ASTM D-97 was followed; the samples were examined at intervals of 1^{0}C, until any cloud was observed at the bottom of the test jar. The cloud point was reported to the nearest 1^{0}C as ASTM D-2500 cloud point Fig-3.

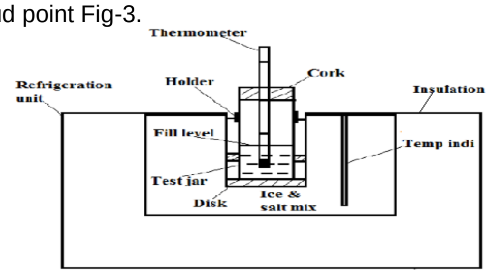

Fig.3.Experimental setup for cloud point

Kinematic Viscosity

The cold climate viscosity of Mahua ester is imperative on considering the spray characteristics of the injector, since the change in spray can greatly alter the combustion properties of the mixture. The esterification of Mahua oil produced a remarkable decrease in values of viscosity measured and it was found that in general, the measured viscosities of methyl ester of Mahua oil was little higher than the values measured for diesel over the higher range of temperatures considered. However, viscosity value of biodiesel fuel in low temperature region is different as compared to petrodiesel.

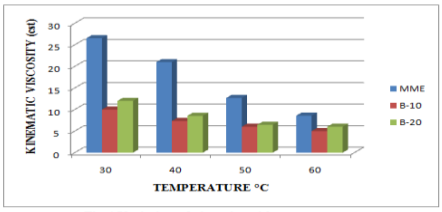

Fig.4.Variation of viscosity with temperature

High viscosity leads to problem in pumping and spray characteristics (atomization and penetration, etc.). The inefficient mixing of oil with air contributes to incomplete combustion. However to blending with petroleum diesel (B-10, B-20) improves the viscosity.The Fig-4 represents the variation of kinematic viscosity with temperature.

Flash Point and Fire Point

The flash and fire point was meaasured with a Cleave land apparatus. Mahua methyl ester has a high value of flash and fire point and blending with petrolium diesel or preheating improves the flash and fire point to a considerable amount. The table-1 gives a comparision of physico chemical properties of Mahua methyl ester with crude Mahua oil and petrolium diesel.

Table 1
Pysicochemical Properties

Property	Petroleum diesel	Mahua oil	MME	ASTM D6751-02	DIN EN14214
Density@ 40^{0}C , kg/m^3	835	945	890	875-900	860-900
Kinematic viscosity @40^{0}C, cst	2.44	47.09	20.99	1.9-6	3.5-5.0
Flash point in ^{0}c	70	226	198	>130	>120
Fire point in ^{0}C	76	250	203	>65	>70

Cloud point ^{0}C	-10 to -15	14	12	Summer =4 Winter= -1	Summer=6 Winter=1
Pour point ^{0}C	-35 to -15	15	8		
Acid value, mg of KOH/gm of oil	NM	30	1.12	<0.8	<0.5
Calorific value(MJ/kg)	43	35	38.863	40 min	49 max
Saponification value	NM	191	130	......	......
Colour	Light brown	Slight greenish yellow	Dark yellow	....	....
Cetane number	47	NM	50	....	....
Iodine value	NM	65	60		
Diesel index	150	140	145	....	....

Engine Setup

Table 2

The Shows the Engine Specification

Engine	Kirloskar TV1
General details	4 stroke CI water coole singlec ylinder computerised.
Bore x Stroke	87.5 mm x 110 mm
Compression ratio	17.5 : 1 (varing from 16:1 to 18.1)
Displacement	661 cc
Power	3.5 kW
RPM	1500

A four stroke,water cooled,single cylinder engine coupled with edicurrent dynamometer was used for present study Fig-5. The engine was computerised with engine soft (software) to measure the engine performance parameters. AVL make gas analyser was employed to note the exhaust emissions such as carbon dioxide,hydro carbon,carbon monoxide,oxygen, and nitrous oxides.

Performance and emission parameters were noted for 100% MME, B-10, B-20, B-30, B-50 and petrolium diesel. The reference study was based on petrolium diesel to interprete the data for comparision.The test was conducted at 1500 rpm with varing loads.

Fig.5.Computerised variable compression ratio engine

Engine Performance

Brake power

The variation of brake power with respect to load for MME (B-100), B-10, B-20, B-30, B-50 and petroleum diesel was considered for present analysis as presented in Fig-6. The brake power of petroleum diesel was found highest from part load to full load, and that of MME was found slightly lower value which is because of higher viscosity and low calorific value of MME than that of diesel. The power loss in B-100 is 5% at full load and 18:1compression ratio however B-10 and B-20 shows a loss of 1 to 2%. Hence 10 -20% blending of MME with petroleum diesel can be recommended in DI engines without any engine modification and adulteration.

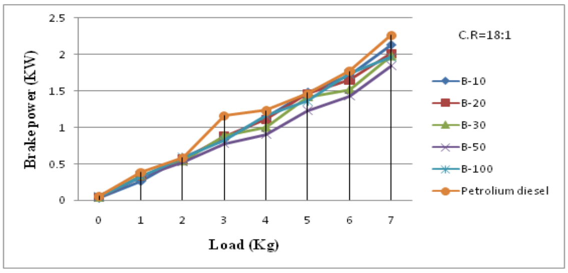

Fig.6.Variation of B.P with load

Brake Mean Effective Pressure

The variation of BMEP with respect to load for MME (B-100), B-10, B-20, B-30, B-50, and petroleum diesel was taken for analysis as presented in Fig-7. The BMEP of petroleum diesel was found highest from part load to full load and that of MME was found lowest value which is because of higher viscosity and low calorific value of MME than that of diesel. The mean effective pressure loss in B-100 is 5% at full load and 18:1compression ratio however B-10 and B-20 shows a loss of 1 to 2%. Hence 10-20% blending of MME with petroleum diesel can be recommended in DI engines without any engine modification and adulteration.

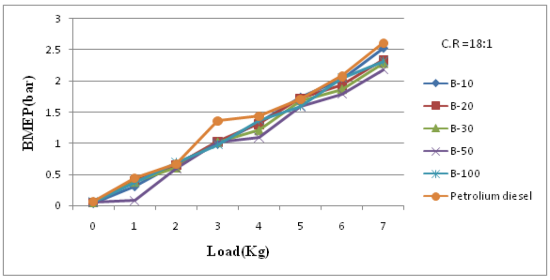

Fig.7.Variation of brake meaneffective pressure with load

Brake Thermal Efficiency

The variation of brake thermal efficiency with respect to load for MME (B-100), B-10, B-20, B-30, B-50, and petroleum diesel was taken for analysis as presented in Fig-8. The brake thermal efficiency of petroleum diesel was found highest from part load to full load and that of MME was found lowest because of higher viscosity and low calorific value of MME than that of diesel. The brake thermal efficiency in B-100 reduces by 5% at full load and 18:1 C.R however B-10 and B-20 shows reduction of 1 to 2%. Hence 10-

20% blending of MME with petroleum diesel can be recommended in DI engines without any engine modification and adulteration.

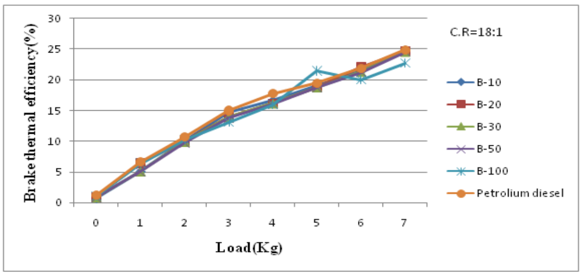

Fig.8.Variation of brakethermal efficiency with load

Specific Fuel Consumption

The variation of specific fuel consumption per kilowatt hour with respect to load for MME (B-100), B-10, B-20, B-30, B-50, and petroleum diesel was taken for analysis as presented in Fig-9. The specific fuel consumption per kilowatt hour of petroleum diesel increases at part load and decreases gradually as the load increases. The profile of petroleum diesel was found above from part load to full load and that of MME was found below which is because of higher viscosity and low calorific value of MME than that of diesel.

The specific fuel consumption per unit power generation for petroleum diesel and B-10, B-20 were very close from part load to full load. Hence 10-20% blending of MME with petroleum diesel can be recommended in DI engines without any engine modification or adulteration.

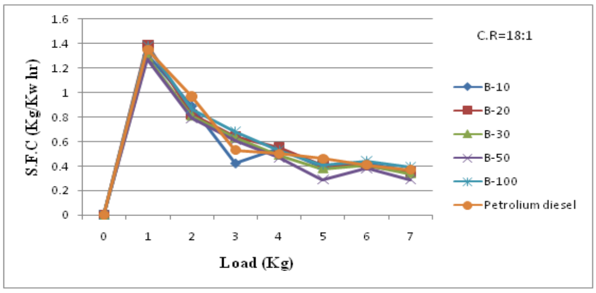

Fig.9.Variation of specific fuel consumption with load

Emission Analysis

Emission Analysis of B-10

The variation in emissions of B-10 with respect to petroleum diesel was considered for analysis as presented in Fig-10. Emission of CO, CO_2 and free O_2 was very close to that of petroleum diesel. Hazardous emissions like un burnt HC and NO_x were considerably less (47%) than that of diesel. So 10% blending of MME with diesel can be recommended for DI engines without any modification or adulteration.

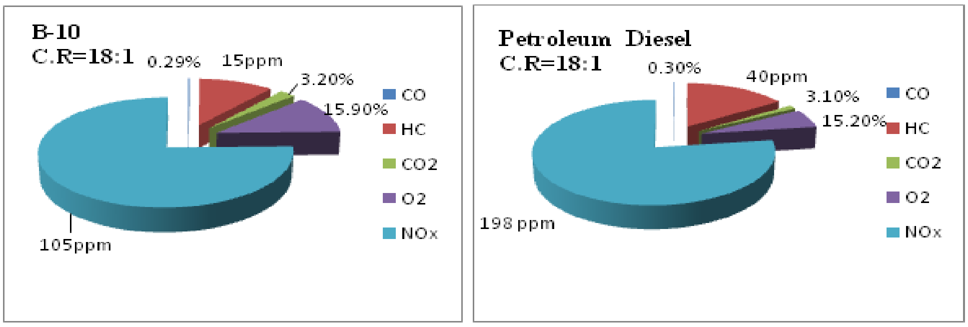

Fig.10.Emission comparision

Emission Analysis of B-20

The variation in emissions of B-20 with respect to petroleum diesel was considered for analysis as presented in Fig-11. Emission of CO, CO_2 and free O_2 was very close to that of petroleum diesel. Hazardous emissions like unburnt HC and NO_x were considerably less (45.45%) than that of diesel. So 20% blending of MME with diesel is slightly low grade fuel in comparison to 10% blending and can be recommended for DI engines without any modification.

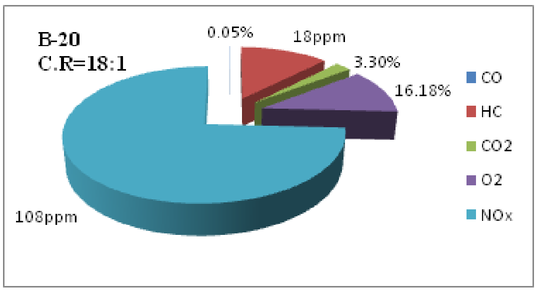

Fig.11.Emission comparion

Emission Analysis of B-30

The variation in emissions of B-30 with respect to petroleum diesel was considered for analysis as presented in Fig-12. Emission of CO, CO_2 and free O_2 was very close to that of petroleum diesel. Hazardous emissions like unburnt HC and NO_x were considerably less (44.4%) than that of diesel. So 30% blending of MME with diesel is slightly low grade fuel in comparison to 10% and 20% blend because of higher viscosity and durability problem.

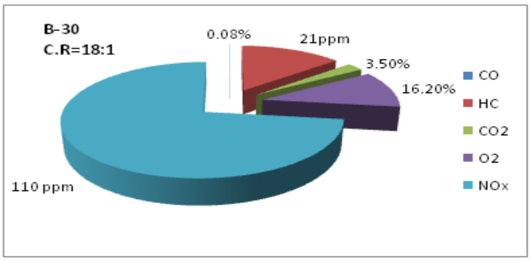

Fig.12.Emission comparision

Emission Analysis of B-50

The variation in emissions of B-50 with respect to petroleum diesel was considered for analysis as presented in Fig-13. Emission of CO, CO_2 and free O_2 was very close to that of petroleum diesel. Hazardous emissions like un burnt HC and NO_x were considerably less (34.34%) than that of diesel. So 50% blending of MME with diesel is slightly low grade fuel in comparison to 10%, 20% and 30% blend because of higher viscosity and durability problem.

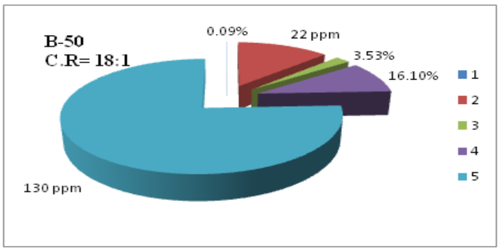

Fig.13.Emission comparision

Emission Analysis of MME (B-100)

The variation in emissions of MME (B-100) with respect to petroleum diesel was considered for analysis as presented in Fig-14. Emission of CO, CO_2 and free O_2 was very close to that of petroleum diesel. Hazardous emissions like un burnt HC and NO_x were considerably less (25.2%) than that of diesel. So absolute MME is a low grade fuel in comparison to 10%, 20%, 30% and 50% blend because of higher viscosity and durability problem.

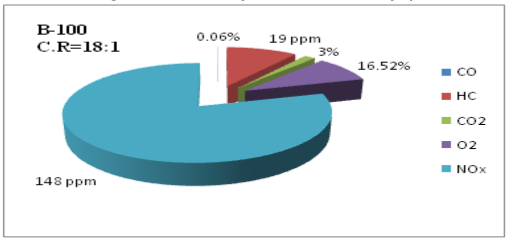

Fig.14.Emission comparision

Aim of the Study

The present study was carried out to optimise the oil extraction and its conversion to methyl ester, characterization of the mahua methyl ester properties as a fuel and evaluation of engine performance. The result shows that B-10 and B-20 was the best engine fuel in D.I engines without any change in engine hardware.

Review of Literature

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Conclusion

This study experimentally analyzed the characteristics of cold flow performance, and exhaust emissions of MME and its proportional blends with petroleum diesel compared with absolute petroleum diesel. The low temperature flow properties of MME are an imperative problem in its use as commercial fuel. Preheating up to 100^0C and subsequent cooling to atmospheric temperature gives propitious results. Blending with diesel in various proportions improves its cold flow properties and viscosity considerably, 10% to 20% blend renders very close results to diesel and can be recommended as bio additive in robust D.I engine combustion without any modification or adulteration. The engine modification in utilising exhaust gas temperature for preheating may mitigate the problem substantially, however higher viscosity, poor cold flow properties and low calorific value of MME predominates its use as an absolute commercial fuel.

The study of exhaust analysis infers contemporary CO, CO_2 and O_2 emissions with petroleum diesel. However unburnt HC, NO_x emission are considerably lower than that of petroleum diesel. Noise level is low without cracking sound as observed in fossil fuel combustion. Thus energy harnessed is a clean energy irrespective of poor cold flow properties and negligible power loss.

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